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Resource Allocation and Optimal Scheduling of Virtual Network Functions in Software Defined Networks

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A thesis submitted in partial fulfilment of the requirements for the degree of

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by

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to

School of Electrical and Data Engineering
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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, *Mahmoud Gamal Ahmed Bekhit* declare that this thesis, submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the *School of Electrical and Data Engineering*, *Faculty of Engineering and Information Technology* at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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Abstract

One of the main challenges that faces the Network Functions Virtualization (NFV) deployment is to optimize the resource allocation of demanded network services in the NFV environment. In this study, new optimization models have been developed to find the near to optimal mapping and scheduling for the incoming Virtual Network Function (VNF) requests. The optimization models are formulated as a multi-objective problem in general where different objectives and constraints can be defined depending on the considered scenarios. In the first formulation, three objectives have been defined, namely, maximizing the number of accepted incoming service requests, optimizing link utilization and minimizing the overall processing time of service requests. The second development includes an optimization problem that considers the nonuniform arrival of the incoming service requests periodically. This optimization problem has been done by maximizing the number of accepted service requests, minimizing the number of bottleneck links, the overall processing time. In the third development, the optimization problem considers the expiry time for those incoming service requests to be processed in the VMs. Moreover, the model considers the uniform and non-uniform arrival of the incoming service requests. Four different objectives and five constraints have been considered to solve this optimization problem. Particularly, the model aims to maximize the acceptance rate, minimize the number of bottleneck links, the overall processing time and the relative processing time. In the fourth scenario, the optimization model has been developed to achieve three objectives functions, namely, minimizing the transmission delays occurring

in every link, minimizing the processing capacity for every VM and minimizing the processing delay at every VM. The optimization model developed in the fifth formulation minimizes the processing time for every accepted service request, and at the same time maximizes the number of accepted service requests. All five scenarios have been treated as both single-objective and multi-objective optimization problems, where two different evolutionary algorithms based on a genetic algorithm have been applied for solving the resulting optimization problems. Via numerical simulations, it is shown that for the first three scenarios, the proposed algorithms solve the problem efficiently and converge to near to the optimal solution. Regarding the latter two scenarios, the numerical evaluations provide an evidence that the algorithms developed in this manuscript are scalable and they outperform the evolutionary algorithms proposed in the literature, namely genetic bandwidth link allocation (GA-BA) and genetic non-bandwidth link allocation (GA-NBA) algorithms.

Dedication

To My Loving Parents, My Lovely Wife, My Future Son, My Beautiful Brothers, My Supportive Family in law, My Amazing Friends And To Everyone That Reads This . . .

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List of Publications

Related to the PhD Thesis :

1. Gamal, M., Abolhasan, M., Lipman, J., Liu, R.P. and Ni, W.,, 2018, *Multi Objective Resource Optimisation for Network Function Virtualisation Requests.*, Proc. 26th International Conference on Systems Engineering (**ICSEng 2018**), pp. 1-7, Sydney, Australia, 2018. IEEE.

2. Gamal, M., Jafarizadeh, S., Abolhasan, M., Lipman, J. and Ni, W.,, 2019, *Mapping and Scheduling for Non-Uniform Arrival of Virtual Network Function (VNF) Requests*, Proc. 90th Vehicular Technology Conference (**VTC2019-Fall**), Hawaii, USA, 2019. IEEE.

3. Gamal, M., Abolhasan, M.,Jafarizadeh, S., Lipman, J. and Ni, W.,, 2019, *Mapping and Scheduling of Virtual Network Functions using Multi Objective Optimization Algorithm*, Proc. 19th International Symposium on Communications and Information Technologies (**ISCIT 2019**), Ho Chi Minh, Vietnam, 2019. IEEE.

4. Gamal, M., Jafarizadeh, S., Abolhasan, M., Lipman, J. and Ni, W.,, *Resource Allocation and Optimization Scheduling for Virtual Network Function Requests.* IEEE Transactions on Vehicular Technology (**IEEE TVT**). (***under review***).

5. Gamal, M., Jafarizadeh, S., Abolhasan, M., Lipman, J. and Ni, W.,, *Optimal Mapping and Scheduling for Virtual Network Function in Software Defined Networks.*

The International Journal of Computer and Telecommunications Networking (**Computer Networks**). (***under review***).

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List of Algorithms

Table 1: NOMENCLATURE

NFV	Network Functions Virtualization
SDN	Software Defined Networking
VM	Virtual Machine
NFV-RA	NFV Resource Allocation
ETSI	European Telecom Standards Institute
HVS	High Volume Server
NS	Network Service
VNF	Virtual Network Function
SFC	Service function chaining
TSP	Telecom Service Provider
NFV-MANO	NFV Management and Orchestration
ILP	Integer Linear Programming
NF	Network Function
SDN	Software Defined Networking
VNFs-SCH	VNFs Scheduling
VNF-FGE	VNF Forwarding Graph Embedding
VNF-FG	Virtual Network Function Forwarding Graph
VNFs-CC	VNFs Chain composition
DPI	Deep Packet Inspector
GA	Genetic Algorithm
DPI	Deep packet inspection
VNFR	Virtual Network Functions Request
GA-BA	Genetic Bandwidth Link Allocation
GA-NBA	Genetic Non-Bandwidth Link Allocation
NS	Network Service
NAT	Network Address Translation
VPNs	Virtual private networks
PGWs	Packet Data Network Gateways
IMSs	IP multimedia subsystems
LDMOAD/DE	The lowest delay multi-objective evolutionary algorithm based on decomposition algorithm.
RU-MOEA/D	Resource Utilization Multi-Objective Evolutionary Algorithm based on Decomposition
SM-MOEA/D	scheduling and mapping multi-objective evolutionary algorithm based on decomposition
SM-NSGA-II	scheduling and mapping Non-dominated Sorting Genetic Algorithm II
NFVI	Network Function Virtualization Infrastructure
NFV-MANO	NFV Management and Orchestration
TSP	telecommunications service provider
VNE	virtual network embedding
VNF-FGs	Virtual Network Function Forwarding Graphs
SFC	Service Function Chaining
SFs	service functions
IETF	The Internet Engineering Task Force
MIQCP	mixed integer quadratically constrained program